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Catch Regulation and Accident Risk: The Moral Hazard of Fisheries' Management

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Abstract *A theoretical model focusing on the interaction between safety and fishery regulation is introduced in order to discuss the fishing units' behavior and the public policies' effect upon fatality rates and cost efficiency in the industry. The optimal welfare outcomes for a nontransferable and transferable vessel quota regime are compared and possible advantages and disadvantages of practicing these fishery regulations are identified. Among other things, the authors recommend the public authorities pay attention to moral hazard effects which may follow when the levels of public risk reducing services are increased.*

Key words Catch and safety regulation, moral hazard, nontransferable and transferable quotas.

Introduction

In Norway the fishing industry has the highest fatality rate of all major occupations (Aasjord 1993). The explanation for this seems evident; the Norwegian fishing fleet operates in areas with rapidly changing natural conditions where strong winds, frigid waters, darkness, and ice constitute a considerable risk for material damages, injuries, and loss of lives. These physical conditions at sea reflect stochastic variables which cannot be affected by any human being. However, researchers, politicians, and other experts have been interested in how fishermen and public authorities can reduce the number of fatalities in the industry [see, for instance, Norges Offentlige Utredninger (NOU) 1986; Norwegian Association of Fishermen 1992; and Farstad 1993]. Participants in the debate seem to agree that captains and crew members of the fishing units can influence the degree of actual fishing risks. Both investment decisions (determining the shape and the size of a vessel) and operating decisions (such as deciding when and where to fish, what kind of and how much fishing tackle, number of crew and hours on duty) affect the actual probabilities of accidents. Furthermore, it is believed that accident risks are also influenced by the level of public services supplied to the operating vessels (such as navigation and communication systems) and by weather forecasts and published charts. In addition, public authorities can increase safety and reduce the consequences of accidents by setting certain types of standards (concerning the stability of the vessel, obligatory

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survival suits, rescue service, *etc.*). In the exchange of views regarding safety regulations, it has also been argued that the public authorities' policy of regulation indirectly affects the fatality rates in the fishing industry by affecting the daily work of fishermen (see for instance Farstad 1993; and Bergland 1995).

Motivated by the well-known need to regulate total effort and total catch volume in common property fisheries (theoretically described in the review by Munro and Scott 1985) and the experience of reduced stocks when fishing was unregulated, the fishery authorities in Norway have in recent years made use of different kinds of regulatory instruments such as license limitation programs, nontransferable vessel quotas, and sometimes contests between fishermen within a global harvest quota. In addition, there is currently an on-going debate whether public authorities, in order to improve efficiency in the fishing industry, should allow fishermen to buy and sell individual vessel quotas.

Based on the discussions of choosing a safety and catch regulation for the fishing industry in Norway, one may ask: (*i*) Is it necessary for public authorities to be concerned about safety in fishing operations at all? (*ii*) If public authorities spend resources on safety regulations in the fishing industry, how do the fishing units react? and (*iii*) does the actual choice of fishery regulation influence the probabilities of accidents in the industry? In order to discuss these questions regarding regulations for the fishing industry, we will in the next section adopt a theoretical model describing how the fishing firm's practice and the public authorities' choice of public services affect production possibilities and risks. Furthermore, this model will be used to deduce a first-best optimal welfare outcome defined by a certain level of effort inserted in the production and safety by each of the fishing units, as well as a certain level of public services supplied to the fishing industry given a predetermined total catch volume (supposed to be the harvest which maximizes the economic or sustainable yield in the fishery). Implicitly, this first-best solution will characterize a socially preferable catch distribution among the vessels when both productivity and safety issues are taken into account. The following section considers what we call feasible public policies where the authorities are supposed to choose levels of public services supplied to the industry before the fishing units choose the levels of effort which maximize their expected profits. In order to focus on the effect the actual choice of fishery regulation might have on the safety in the industry, this analysis is carried out in relation to both transferable and nontransferable quota systems. Finally, after the different results are discussed and compared, the last section draws some conclusions.

The Model and Optimal Welfare Outcome Given a Global Catch Target

In order to analyze behavior in the fishing industry and the socially preferable outcome, we will present a simple model describing how the firm's choices of inputs and the public authority's choice of safety installations will affect production and risks, and thereby the expected profits stemming from the fishery. The model is inspired by the seminal work on traffic safety regulation by Peltzman (1975) and later applied by several economists to discuss different kinds of moral hazard problems following from public interventions (see, for instance, Diamond 1977; Viscusi 1979, 1985; Blomquist 1986; Shavell 1987; Jones-Lee 1989; Risa 1992; and Jørgensen 1993). First, we suppose that a typical fishing firm f faces an exogenous production technology given by the function

$$R^f = R^f(v^f, s),\ f = 1, \dots, F \tag{1}$$

$$\frac{\partial R^f}{\partial v^f} = R_v^f > 0, \frac{\partial R^f}{\partial s} = R_s^f > 0$$

$$\frac{\partial^2 R^f}{(\partial v^f)^2} = R_{vv}^f < 0, \frac{\partial^2 R^f}{\partial s^2} < 0$$

where R is firm f's catch volume, v is a vector describing firm f's choice of inputs and s is measuring the fishing authorities' choice of installations used by all of the firms in their production, such as the quantity and quality of the charts, weather forecasts, and radio-signals used by the operators in navigating and communicating. In order to simplify the analyses, however, s is considered as a uniform variable which appears as a public good in the fishing industry. Moreover, the production function in equation (1) is assumed to have the standard neoclassical characteristics (*i.e.*, increasing and concave in the arguments). Second, we introduce the prevention technology for the fishing firm f by the function

$$p^f = p^f(n^f, z^f, s) \tag{2}$$

$$p^f \in (0,1]$$

$$p_n^f = \frac{\partial p^f}{\partial n^f} < 0, \; p_z^f = \frac{\partial p^f}{\partial z^f} > 0, \; p_s^f = \frac{\partial p^f}{\partial s} < 0$$

where p^f is the probability of an accident in fishing firm f. Furthermore, it is assumed that higher levels of public services will reduce the accident risks in the fishing industry. For the sake of simplicity, we will only specify two types of inputs chosen by each of the firms, $v = (n, z)$, where n describes an input which is safety-improving, *i.e.*, number of men or level of care taken by the fishing operator, and z is an input which is safety-worsening, *i.e.*, the work intensity, the fishing time, or the number of fishing tackles used by the boat. In the case of an accident, the total loss for boat f, L^f, is assumed to be the sum of the private or internal loss experienced by the operator, L_i^f, (*e.g.*, costs of missed catch, fishing tackles, and other capital equipment) and the external costs, L_e^f experienced by the public sector (*e.g.*, the costs of search and rescue operations), other firms (*e.g.*, more expensive accident insurance) and family and friends who experience negative economic and social losses if the accident causes fatal or serious injuries to the life or health of any crew members. The distribution of the total loss on internal and external loss for a fishing boat is dependent on the insurance contract. Higher levels of insurance will reduce the internal loss and increase the external costs. Furthermore, it is likely that the distribution of loss is dependent on whether members of the crew are owners and therefore decision makers in the firm. If an owner is a member of the crew and is injured, it is likely that the possible losses experienced by families and friends are internalized and therefore can be considered as internal losses. However, in the opposite case, where the owner does not participate in the fishing operations, it is likely that possible losses to the crew members and their relatives must be considered as external costs if an accident occurs. Without respect to the distribution of the costs in the case of an accident, we assume for the sake of simplicity, that the size of the total loss is independent of the action actually chosen by the firm and the public authority.

Furthermore, it is assumed that the public authority supplying the safety-improving technology s used by the fishing firms has costs which can be specified by the function $C = C(s)$, where the costs are increasing and convex in the argument, *i.e.*, $C'(s) > 0$ and $C''(s) \geq 0$. We can now define the expected profit of fishing firm f by

$$\pi^f = R^f(n^f, z^f, s) - wn^f - qz^f - p^f(n^f, z^f, s)L_i^f$$

where we have normalized the fixed price of the fish to 1 and where w and q are the prices of the safety-improving and safety-worsening inputs respectively. If we assume that there are F fishing firms in the industry, the welfare stemming from the activity can be defined by

$$W = \sum_{f=1}^{F} (\pi^f - p^f L_e^f) - C(s) \tag{3}$$

Maximizing equation (3) with respect to n, z, and s, given a global catch target $\sum_{f=1}^{F} R^f = \overline{R}$, yields the following necessary conditions for a first-best optimal welfare allocation of the resources in the industry

$$(1 - \lambda)\frac{\partial R^f}{\partial z^f} = q + \frac{\partial p^f}{\partial z^f} L^f \tag{4}$$

$$(1 - \lambda)\frac{\partial R^f}{\partial n^f} = w + \frac{\partial p^f}{\partial n^f} L^f$$

$$\sum_{f=1}^{F}\left[(1 - \lambda)\frac{\partial R^f}{\partial s} - \frac{\partial p^f}{\partial s} L^f\right] = C'(s)$$

where λ is the marginal resource rent. It is easily seen from equation (4) that in the case where the firm's choices of inputs do not influence upon the accident risks and there is a nonbinding resource condition ($\lambda = 0$), we get the standard first order conditions. The value of the marginal product of each of the inputs chosen by the firm should be equal to the input prices and aggregated value of the marginal product of the public services for all operating firms should be equal to the marginal cost of supplying public services. If the resource condition is binding, the social value of catching an extra unit of fish is given by $(1 - \lambda)$, implying the marginal values of the products, in welfare terms, is reduced compared to the nonbinding case. Furthermore, if the probability of an accident is affected by the actual choices of the private and public inputs, there will be additional expected social costs by using the safety-worsening input z and additional expected social gains by using the safety-increasing inputs n and s.

Feasible Public Policies

If the welfare allocation discussed above is to be used to design a policy for the fishing industry, the public regulator must know the individual firm's production and prevention functions in equations (1) and (2), and, additionally, be able to choose the levels of inputs in all firms. Therefore, it is practically impossible for a public authority to implement the first-best optimal welfare allocation directly. Feasible policies must be based on fishing firms which individually choose levels of private inputs and a public authority choosing the size of the public supply of installations affecting production and safety conditions in the industry. Furthermore, it is believed that fishing firms, before they adjust the quantities of private inputs, can observe and react to the chosen levels of public services. The equilibrium of such a two-stage principal agent game, where the authority (principal) first chooses public supply of effort, improving productivity and safety in the industry, whereafter the fishing operators (agents) decide upon levels of private inputs, can be found by backward induction. First, we will characterize the fishing firm's optimal behavior, given that they all maximize expected profits for a given supply of public input and given a certain quota regime. The conditions describing the firm's optimal behavior are discussed in the case where the quotas are transferable, and in the case where such transfers are illegal. Moreover, the firm's possible response on changes in public supply of the safety and production improving input are analyzed. Second, the authority's optimal choice of public services when quotas are transferable and when quotas are nontransferable, given the fishing firm's possible reactions on changes in the levels of public services, is analyzed. Finally, we compare feasible public policies in the case of transferable and nontransferable vessel quotas by referring to the first-best allocation deduced in the previous section of this paper.

The Firm's Optimal Behavior and Their Responses to Changed Levels of Public Input

If the vessel quotas are nontransferable, the problem for a risk-neutral fishing firm will be to maximize the firm's expected profits with respect to the individually controlled inputs, given the size of quota and the level of public input, *i.e.*,

$$\max_{n^f, z^f}\left[R^f(n^f, z^f, s^0) - wn^f - qz^f - p(n^f, z^f, s^0)L_i^f\right]$$

given

$$R^f(n^f, z^f, s^0) \leq r^f$$

where r^f must be interpreted as the size of the exogenous vessel quota decided by the fishing authority. Furthermore, if the quotas are transferable between the vessels, the problem of a fishing firm can be formulated by

$$\max_{n^f, z^f}\left\{R^f(n^f, z^f, s^0) - k\left[R^f(n^f, z^f, s^0) - r^f\right] - wn^f - qz^f - p(n^f, z^f, s^0)L_i^f\right\}$$

where r^f is still the size of the quota given to fishing firm f, but now the firm can choose to sell (some of) the available catch or buy additional quotas from other vessels. The price for each unit sold or bought, k, is assumed to be a price which clears the quota market.[1]

In general, the conditions defining the equilibria under these two quota regimes can be formulated by

$$(1 - \lambda^f)\frac{\partial R^f}{\partial z^f} - q - \frac{\partial p^f}{\partial z^f}L_i^f = 0 \tag{5}$$

$$(1 - \lambda^f)\frac{\partial R^f}{\partial n^f} - w - \frac{\partial p^f}{\partial n^f}L_i^f = 0$$

$$\sum_{f=1}^{F} R^f(n^f, z^f, s^0) = \sum_{f=1}^{F} r^f$$

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[1] Alternatively, this problem could have been formulated as individual maximizations of the fishing firm's expected profits, given that the total catch quantity is less than or equal to the sum of the individual quotas.

where λ^f in the case of nontransferable quotas must be interpreted as the potential gain in expected profit in firm f by allowing this firm to catch an additional unit, generally varying among the operators ($\lambda^f \neq \lambda^g$, $f, g = 1, \ldots, F$, $f \neq g$), and interpreted as the quota price k, faced by all of the firms in the case of transferable quotas, ($\lambda^f = k$, $\forall f = 1, \ldots, F$).

Under both quota regimes it is seen from equation (5) that the marginal rate of substitution between the two private inputs in firm f, $(\partial R^f/\partial z^f)/(\partial R^f/\partial n^f)$, will in equilibrium be equal to $[q + (\partial p^f/\partial z^f)\, L_i^f\,]/[w + (\partial p^f/\partial n^f)\, L_i^f\,]$. Compared to the optimal welfare conditions in equation (4), given that firm f faces a lower private loss in the case of an accident than the total social loss, *i.e.*, $L_e^f > 0$, it is seen that the private operator would use too much of the safety-worsening input z and too little of the safety-increasing input n for any catch level. This result follows from the existence of an externality. In fact, the externality affects both the use of n and z. Firstly, if a private firm increases the safety-worsening input (z), it will experience a higher increase in private expected profits than the effect this higher level of z has on expected social welfare. This will result in lower private than social expected costs in the fishing industry. Secondly, an increase in the private safety-increasing input (n) means higher expected welfare than the increase in the firm's expected profits. This effect means higher private expected costs in the fishing industry than the expected social costs. Hence, whether we have a positive or negative externality concerning the firm's catch quantities, is conditional on the sizes of the effects commented on above.

In general, it is seen that the distribution of the total catch might result in inefficiency in the fishing industry. In the case of nontransferable quotas this is obvious. The public authority, which *ex ante* gives each of the fishing firms a quota, does not know the production and prevention functions of all firms in detail, and is therefore unable to distribute the total catch efficiently, which is characterized by the condition that the marginal social welfare with regard to the size of the catch should be equal for all vessels. However, let us first compare the catch distribution for the two quota regime. It is easily seen that if $k \geq (<) \lambda^f$, then $r^f \geq (<)\ R^f(n^f, z^f, s)$, *i.e.*, when the marginal profit gain in catching an extra unit for the firm in the case of nontransferable quotas is lower (higher) than the quota price, the catch quantity will be lower (higher) in the transferable than the nontransferable case. Thus, the fishing firm, given the quota r^f, will sell some of the catch quantity (buy an additional catch quantity) if it becomes legal.

Let us now compare the first-best welfare allocation and the outcome in the case of transferable quotas. If it is legal to transfer quotas, the expected private profits for the last caught units will be the same for all fishing firms in equilibrium (equal to k), but the expected welfare gain for the last unit caught on a vessel might be different from the marginal social welfare. If $k > (<)\ \lambda$, the equilibrium in the case of a transferable quota regime, where the firms individually maximize expected private profits, is characterized by fishing firms which on average underestimate the expected marginal social costs regarding the usage of the safety-worsening input more (less), then they underestimate the expected marginal social utility regarding the usage of the safety-increasing input. In other words, the private marginal cost in catching the last unit given the transferable quota regime is lower (higher) than the social marginal costs. If the difference between the expected marginal social welfare and the profit is negative (positive) and identical for all fishing firms, the total allowable catch will be efficiently distributed among the operating vessels, but the quota price over (under) estimates the social value of the last unit caught. In general, however, it is believed that the differences between the social and private marginal gain may vary among the fishing units, implying an inefficient catch distribution. If $k > (<)\ \lambda$, the firms, characterized by the highest deviations between their private and their social marginal costs, will catch too much (less) in the transferable quota regime compared to the first best welfare optimal distribution of the total allowable catch quantity.

The conditions defining the fishing firm's optimal behavior above will hold for any level of the public input s, *i.e.*, the individually optimal levels of n and z, defined by equation (5), are functions of the public input s, $n^f = n^f(s)$ and $z^f = z^f(s)$, $f = 1, \ldots, F$. It then follows that the impact of changed public supply on a firm's behavior is generally given by

$$\frac{dn^f}{ds} = \frac{-\pi^f_{ns}\pi^f_{zz} + \pi^f_{zs}\pi^f_{nz}}{\pi^f_{nn}\pi^f_{zz} - (\pi^f_{nz})^2} \tag{7}$$

$$\frac{dz^f}{ds} = \frac{-\pi^f_{nn}\pi^f_{zs} + \pi^f_{nz}\pi^f_{ns}}{\pi^f_{nn}\pi^f_{zz} - (\pi^f_{nz})^2}$$

where

$$\pi^f_{nn} = (1-\lambda^f)R^f_{nn} - p^f_{nn}L^f_i < 0$$

$$\pi^f_{zz} = (1-\lambda^f)R^f_{zz} - p^f_{zz}L^f_i < 0$$

$$\pi^f_{nn}\pi^f_{zz} - (\pi^f_{nz})^2 > 0$$

$$\pi^f_{nz} = (1-\lambda^f)R^f_{nz} - p^f_{nz}L^f_i$$

$$\pi^f_{ns} = (1-\lambda^f)R^f_{ns} - p^f_{ns}L^f_i$$

and

$$\pi^f_{zs} = (1-\lambda^f)R^f_{zs} - p^f_{zs}L^f_i$$

The signs of the expressions stated above are the sufficient conditions for the maximum solutions defined by equation (5). Moreover, to be able to determine the signs of dn^f/ds and dz^f/ds, it is seen from equation (6) that we have to make further assumptions concerning the production and prevention functions. First of all, it seems likely that $\pi^f_{zs} > 0$ because $R^f_{zs} > 0$ and $p^f_{zs} < 0$. Positive R^f_{zs} means that z and s are presumed to be technical complements, *i.e.*, as s becomes higher, the productivity of the firm's safety-worsening input increases. For instance this condition reflects that better weather forecasting and navigation systems make any levels of the firm's fishing tackles more effective in production. Furthermore, negative p^f_{zs} implies that as s becomes higher, the less influence a marginal change in z has on the probability of loss. If the assumption concerning π_{zs} above holds, in isolation, an increase in the public services will lead to increased quantity of the safety-worsening input, which increases the probability for accidents. However, the total effect of increased public services will also be conditional on the signs and sizes of π^f_{ns} and π^f_{nz}, which are more difficult to determine based on reasonable presumptions. However, it follows from equation (6) that if $\pi^f_{zs} > 0$ and the signs of π^f_{ns} and π^f_{nz} are generally ambiguous, it is possible to illustrate the effects on the private inputs for marginal changes in s in the table below.

From table 1 it is seen that even though we restrict our discussions to cases where $\pi_{zs} > 0$, generally we cannot draw any conclusions regarding the signs of dz^f/ds and dn^f/ds. For instance, the direct positive effect on z caused by an increase in s might be dominated by a negative indirect effect. Higher s will also affect z through a changed level of n, and when $\pi_{ns} > 0$ and $\pi_{nz} < 0$, or $\pi_{ns} < 0$, and $\pi_{nz} > 0$, this (indirect) effect will be negative, resulting in an unambiguous sign of the total effect measured by dz^f/ds.

As already noticed, the direct effect on n caused by an increase in s might be positive, zero, or negative conditional on whether $\pi_{ns} > 0$, $\pi_{ns} = 0$, or $\pi_{ns} < 0$. Whether the sign of the total effect on n for changed levels of public services is

Table 1
Effects on Private Inputs Caused by Marginal Changes in Public Services when $\pi_{zs} > 0$.

	$\pi^f_{nz} < 0$	$\pi^f_{nz} = 0$	$\pi^f_{nz} > 0$
$\pi^f_{ns} < 0$	$\frac{dn^f}{ds} < 0$ $\frac{dz^f}{ds} > 0$	$\frac{dn^f}{ds} < 0$ $\frac{dz^f}{ds} > 0$	$\frac{dn^f}{ds}\ ?\ 0$ $\frac{dz^f}{ds}\ ?\ 0$
$\pi^f_{ns} = 0$	$\frac{dn^f}{ds} < 0$ $\frac{dz^f}{ds} > 0$	$\frac{dn^f}{ds} = 0$ $\frac{dz^f}{ds} > 0$	$\frac{dn^f}{ds} > 0$ $\frac{dz^f}{ds} > 0$
$\pi^f_{ns} > 0$	$\frac{dn^f}{ds}\ ?\ 0$ $\frac{dz^f}{ds}\ ?\ 0$	$\frac{dn^f}{ds} > 0$ $\frac{dz^f}{ds} > 0$	$\frac{dn^f}{ds} > 0$ $\frac{dz^f}{ds} > 0$

positive, zero, or negative, however, is also conditional on the sign and size of the indirect effect s has on n through a changed level of z.

In our further discussions we will pay special attention to the cases where there is a moral hazard problem, *i.e.*, that the fishermen behave in a way which increases risks. From table 1, it is seen that such a behavior is generally found when $\pi_{ns} \leq 0$ and $\pi_{nz} \leq 0$ (in addition to $\pi_{zs} > 0$). Higher supply of public services then induces the firm to increase z and to reduce n (unchanged if the equalities occur), which means higher probabilities for losses. Hence, a sufficient condition for this double moral hazard problem to arise is that the marginal expected profit with respect to n is decreasing in z and s.

For simplicity, if we believe that $p^f_{nz} = p^f_{ns} = 0$, in other words, that the marginal reduction in the probability of loss with respect to n is independent of z and s, the sufficient condition holds when the pairs n and s and n and z are substitutes in production ($R^f_{ns} < 0$ and $R^f_{nz} < 0$).

It should be remarked that even though such a double moral hazard problem may exist, the total effect on the probability of loss for a fishing unit caused by higher supply of public services will reduce the fatality rates if

$$-p^f_s > \left| p^f_n \frac{dn^f}{ds} + p^f_z \frac{dz^f}{ds} \right|$$

i.e., that the direct reduction in the accident probability caused by an increase in public input dominates the possible increase in the accident probability this effect indirectly causes though changed levels of the private inputs.

Optimal Level of Public Services, Given the Firm's Individual Behavior

When the public authorities choose the level of installations affecting the safety and production conditions among operating vessels, they know the individual reactions to the private inputs discussed above. In the case of nontransferable quotas, the public authority's problem will be to maximize

$$\sum_{f=1}^{F}\left\{R^f\left[n^f(s), z^f(s), s\right] - wn^f(s) - qz^f(s) - p\left[n^f(s), z^f(s), s\right](L_i^f + L_e^f)\right\} - C(s)$$

with respect to s, given that $R^f[n^f(s), z^f(s), s] \le r^f$, $f = 1, \ldots, F$.

In the case of transferable quotas, the problem can be formulated by

$$\max_s\left[\sum_{f=1}^{F}\left\{(1-k)R^f\left[n^f(s), z^f(s), s\right] - wn^f(s)\right.\right.$$
$$\left.\left. - qz^f(s) - p^f\left[n^f(s), z^f(s), s\right](L_i^f + L_e^f)\right\}\right] - C(s)$$

where k is determined by

$$\sum_{f=1}^{F} R^f\left[n^f(s), z^f(s), s\right] = \sum_{f=1}^{F} r^f .$$

The first order condition defining the public authority's (or the principal's) optimal choice of s, when the fishing units (or the agents) have the possibility to respond to the actual level of public input chosen, can generally be written by

$$\frac{\partial W}{\partial s} = \sum_{f=1}^{F}\left\{\left[\underbrace{(1-\lambda^f)\frac{\partial R^f}{\partial n^f} - w - \frac{\partial p^f}{\partial n^f}L_i^f}_{=0}\right]\frac{\partial n^f}{\partial s} + \left[\underbrace{(1-\lambda^f)\frac{\partial R^f}{\partial z^f} - q - \frac{\partial p^f}{\partial z^f}L_i^f}_{=0}\right]\frac{\partial z^f}{\partial s}\right\} \quad (7)$$
$$+\sum_{f=1}^{F}\left\{(1-\lambda^f)\frac{\partial R^f}{\partial s} - \left[\frac{\partial p^f}{\partial n^f}\frac{\partial n^f}{\partial s} + \frac{\partial p^f}{\partial z^f}\frac{\partial z^f}{\partial s}\right]L_e^f - \frac{\partial p^f}{\partial s}\left[L_i^f + L_e^f\right]\right\} - C'(s) = 0$$

where $\lambda^f \ne \lambda^g$, $f, g = 1, \ldots, F$, $f \ne g$ when the quotas are nontransferable and $\lambda^f = \lambda^g = k$, $f, g = 1, \ldots, F$, $f \ne g$ when the quotas are transferable.

Using the conditions describing individually rational behavior in equation (5), leads to the conclusion that the sum of the expressions in the first line in equation (7) is equal to zero. Hence, the necessary condition for an optimal welfare level of public services can be expressed by

$$\sum_{f=1}^{F}\left\{(1-\lambda^f)\frac{\partial R^f}{\partial s} - \left[\frac{\partial p^f}{\partial n^f}\frac{\partial n^f}{\partial s} + \frac{\partial p^f}{\partial z^f}\frac{\partial z^f}{\partial s}\right]L_e^f - \frac{\partial p^f}{\partial s}L^f\right\} = C'(s)$$

The left-hand-side reflects the expected marginal welfare gain by increasing s and the right-hand-side measures the marginal costs with respect to s.

In order to discuss the difference between these feasible policies under the two quota regimes and the optimal welfare allocation analyzed previously, let us compare the condition in equation (7) to the third equation in (4). First, we notice that the marginal welfare stemming from higher public services is lower when the (double) moral hazard problem exists, i.*e.*,

$$p_n^f \frac{dn^f}{ds} + p_z^f \frac{dz^f}{ds} > 0.$$

The existence of this moral hazard problem therefore leads to a lower level of the public service supplied to the fishing industry in the second-best compared to the first-best solution.

Additionally, it is seen that the sum of the marginal social income in equation (7) is found by using the weights $(1 - \lambda^f)$, while the weight for all fishing units is equal to $(1 - \lambda)$ in the first-best allocation case. Comparing the outcome for a transferable quota regime with the first-best solution, shows that in all cases where $\lambda \neq k$, the marginal aggregated social income stemming from an increase in s will be different. If k >(<) λ, *i.e.*, that the negative effect caused by too high level of z dominates (is dominated by) the potential positive effect of an increasing n, resulting in lower (higher) private than social expected marginal costs, then there will be a lower (higher) level of public services in the second-best compared to the first-best solution.

Hence, if the quota price overestimates the marginal welfare gain by the last unit caught ($k > \lambda$) and the double moral hazard effect appears, it is unambiguously clear that the public authorities choose a lower level of s in the second-best than in the first-best case.

To complete the comparisons, let us take a look at the second-best solution in the cases where the quotas are transferable and nontransferable. It is seen from equation (7) that if the λ's are positively (negatively) correlated with the marginal income with respect to s [cov(λ^f, R_s^f) >(<) 0], the total marginal income for the fishing industry with respect to s will be lower (higher) in the nontransferable than in the transferable case. Therefore, if cov(λ^f, R_s^f) >(<) 0, it would be advantageous for the public authorities to choose a lower (higher) level of public services in the nontransferable than in the transferable case. To see this, let us suppose that cov(λ^f, R_s^f) > 0. Then the vessels which are mostly restricted in the case of nontransferable quotas (*i.e.*, the fishing units which have the highest λ-values and which are the potential buyers of quotas), are the vessels which are able to utilize a marginal increase in the public supply most. In a nontransferable quota regime, they will not be able to do so. However, if the vessels under a transferable quota regime which would have sold catch quantities have the highest marginal utility of increased public supply cov(λ^f, R_s^f) < 0, this would make an increase in public supply more welfare improving in the nontransferable case compared to the transferable case. This would lead to a higher level of supply of the public services. However, it seems worthwhile to point out, that the efficiencies of the different fishing units (or the λ levels) will hardly be observable by the public authorities.

Concluding Remarks

According to the questions raised in the introduction we can conclude as follows: (*i*) The public authorities' engagement in safety issues is necessary in order to secure a supply of public goods like communication and navigation systems used by all vessels. In addition, to reduce accident risks, the supply of public services will increase the production possibilities in the fishing industry. However, related to question (*ii*), we have seen that the supply of public services might induce the individual rational fishermen to behave in a way which increases risks because they may insert less of the safety-reducing and more of the safety-increasing private inputs as long as the total losses experienced when accidents happen are higher than the losses each of the fishermen are faced with, *i.e.*, moral hazard effects might occur.

It is more difficult to give a clear answer to question (*iii*) based on the discussion of transferable and nontransferable quota regimes. We have seen that the choice of nontransferable or the transferable quota regimes is conditional on the sizes of the externalities and possible moral hazard effects, which, among other things, are dependent on possible variations in the distribution of the total losses on internal and external accident costs among the vessels. For instance, if the public authorities know the size and the distribution of the total losses for all of the operating units, it will be preferable, in order to minimize the external effects, to give most of the quotas to the vessels where the external costs are small compared to firms where these are high, and forbid the fishermen to transfer catch quantities between them.

Our analysis, based on a simple theoretical model is, as far as we know, one of the first attempts to focus on the interesting question on how fishery and safety regulations affect the welfare in the fishing industry. In the future, more realistic theoretical and empirical analyses should be undertaken. For instance, in addition to focusing on the operating decisions for the fishing firms, it is important to analyze the effect the fishing units' investment decisions might have on safety issues, perhaps also when the operators' attitude towards risks is more complicated than our risk neutral presumption reflects. Furthermore, it would be useful to analyze the effect of other fishery regulations in addition to those explicitly focused on here. Finally, and of primary importance, we believe that empirical studies are needed in order to test whether risks are affected by the actions of the fishermen and the public authorities, and, eventually, to determine the size of such effects.

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